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THERMOMETRICAL EXPERIMENTS

AND

OBSERVATIONS.

By TIBERIUS CAVALLO, F. R. S.

Who was nominated by the President and Council to prosecute Discoveries in Natural History, pursuant to the Will of the late HENRY BAKER, Esq. F. R. S.

Read at the ROYAL SOCIETY, June 15, 1780.

THERMOMETRICAL EXPERIMENTS, &c.

HAVING been appointed by the President and Council of the Royal Society to write the annual dissertation, pursuant to the institution of HENRY BAKER, Esq. F. R. S. I determined to present to the Society the following account of some thermometrical experiments and observations, the greatest part of which were made as long ago as the year 1776. The course of those experiments having been often interrupted by mechanical defects in the construction of instruments, and by various other circumstances, must not be considered as complete investigations of the proposed views, but rather as first attempts, which are to be prosecuted in case of better opportunities. They contain a few facts, which to me seem new and worthy of notice; and, perhaps, the observations concerning the construction and use of the instruments useful in experiments of this sort, may be of use to those persons who have the opportunity, and are willing, to prosecute this experimental inquiry.

Having read in a volume of the Philosophical Transactions the account of an experiment made with a thermometer, whose bulb was painted black, and was exposed to the rays of the Sun, in which case it had been found, that the thermometer shewed a much greater degree of heat than when not blackened, I was desirous of trying the ultimate limits of this difference. For which purpose I constructed two thermometers, the scales of which (being made by trial) coincided so perfectly well together, that when the thermometers were put in equal circumstances, no difference could be perceived between the degrees of heat shewn by them. The method used to graduate those thermometers is as follows. The scale of one of the thermometers was made in the usual manner, *viz.* by finding the boiling and freezing water points, and dividing that distance into 180 equal parts, which are the degrees according to FAHRENHEIT. Here no regard was paid to the barometrical height at the time of finding the boiling water point, it being useless for the experiment for which the instrument was intended. This done, the balls of the two thermometers were put into hot water, and according as the water cooled, and consequently the mercury descended in the tubes, different marks were put upon the tube of the ungraduated thermometer,

which were nominated after the degree of heat shewn at the same time by the graduated thermometer. Thus, for instance, a mark was put at 140° , another mark was put at 135° , another at 130° , and so on. It is plain, that in those points, the thermometers when put in equal circumstances, must coincide perfectly together. Now, on making the scale those points are marked first, and as the distances between those marks were very small (consisting of a few degrees) they were divided with the compasses in the proper number of equal parts or degrees; and in this manner the scale of the other thermometer, was completed, by which means, although these two thermometers did not coincide so well with other thermometers, yet they coincided perfectly well together, as must inevitably be the case, even upon the supposition that their tubes were not perfectly cylindrical. The length of a degree on the scale of those thermometers was a little more than $\frac{1}{20}$ th of an inch, and although those scales were divided into degrees only, yet by inspection a person a little versed in these observations could easily distinguish the height of the quicksilver within a quarter of a degree.

These thermometers were both fixed upon the same frame at the distance of about one inch from one another, having the balls quite detached from the frame, and in this manner they were exposed to the Sun, or to the light of a lamp.

When these thermometers were exposed to the Sun, or kept in the shade, they shewed the same degree precisely. The difference between the degree shewn by these thermometers when exposed to the Sun, and when kept in the shade at about the same time of the day, was very trifling.

When the ball of one of those thermometers, which we shall call A, was painted black with Indian ink, or with the smoke of a candle, and that of the other thermometer B was left clean, on being exposed to the Sun they shewed different degrees of temperature; the quicksilver in the tube of A was much above the quicksilver in the tube of B. This difference sometimes amounted to about 10° . but it was never constant, varying according to the clearness of the Sun's light as well as of the air, and also according to the different degrees of temperature of the atmosphere.

Keeping the frame with those thermometers, one of which had the ball painted black, hung on the side of a window, I observed a remarkable fact, *viz.* that these thermometers shewed unequal degrees of heat, not only when presented to the Sun, but also when exposed to the strong day-light. I cleaned the bulb of the thermometer A, and blackened that of B, but the effect was constant, *viz.* the quicksilver in the tube of the thermometer:
whose

whose bulb was painted black, was constantly higher than the other, whenever they were exposed to the strong day-light. This difference was commonly about one-third of a degree, but sometimes it amounted to three-fourths, and even to a whole degree. The situation in which those thermometers were usually placed was such that the light of the Sun could not be reflected upon them by any object standing before; but the experiment answered even when the Sun was hidden by clouds.

This observation seemed to shew that, perhaps, every degree of light is attended with a proportionate degree of heat; and induced me to try, in a similar manner, whether, by directing the concentrated light of the Moon upon the blackened ball of one of these thermometers, I could render sensible the effect of that light ^(a). But although I attempted it some time ago with a large lens several times, and have lately tried it again with a burning mirror of eighteen inches diameter, yet sometimes for want of proper means of observing the height of the mercury in the tubes of the thermometers, sometimes for want of a continued clear light of the Moon, and in short from one unfavourable circumstance or

(a) The concentrated light of the Moon has often been thrown upon thermometers without any effect; but I do not know that any blackened thermometer was ever used before for this purpose.

other,

other, I have not yet been able to make a fair and decisive trial of this experiment.

The light of the Sun being very inconstant on account of clouds and of its diurnal motion, I thought to make some experiments with the above mentioned two thermometers, by exposing them to the light of a lamp, and I found that this light had a considerable effect upon them.

The ball of one of the thermometers being blackened, and both being set at two inches distance from the flame of a lamp, they both rose from 58° , at which the mercury stood before the lighting of the lamp, to $65^{\circ}\frac{1}{2}$, and the blackened thermometer to $67^{\circ}\frac{1}{2}$. Another time, being set at the same distance from the lamp, the uncoloured thermometer came up to $67^{\circ}\frac{3}{4}$, and the blackened one to $68^{\circ}\frac{3}{4}$. In short, by various repeated trials it appeared, that the difference generally amounted to about 1° . When the thermometers were put farther than two inches from the lamp, this difference decreased, and at about fourteen or fifteen inches it vanished quite.

It is mathematically true, that emanations which proceed from a center, and expand in a sphere, must continually become more and more rare in proportion to the squares of the distances from the center. Thus it is said, that the intensity of light proceeding from a luminous
body

body at the double, treble, quadruple, &c. of a given distance from that body, must be respectively four, nine, sixteen times less dense. The same thing may be said of heat.

Being willing to ascertain this truth by actual experiment, I placed several thermometers, whose balls were not painted, at different distances from the flame of the lamp, and expected to find, when the thermometer at four inches distance was 1° above that placed at eight inches distance, the thermometer placed at two inches distance should be 4° higher. But upon trying this experiment various times, placing the thermometers at different distances from the flame of the lamp, and making the proper calculations agreeable to those distances, it appeared, that the intensity of the heat did not decrease exactly in the duplicate proportion of the distances from the flame of the lamp, but shewed a very odd irregularity. It seemed to decrease faster than the duplicate proportion of the distances for the space of two inches and a half or three inches, after which it decreased much slower. Whether this effect may be attributed to some different state of the air's purity at different distances from the flame of the lamp, or to the vapours proceeding from the flame, I cannot take upon me to determine.

The

The above mentioned experiments gradually induced me to try the effect of the light of the Sun and of a lamp upon thermometers whose balls were painted with different colours. Dr. FRANKLIN's experiment with the pieces of cloth set upon snow that was exposed to the Sun is very well known. The doctor found, that those pieces of cloth, whose colour was darker, sunk deeper in the snow than the others, by which it appears, that they became hotter. My view was to examine those different degrees of heat imbibed by different coloured substances with precision, in order to observe if they kept any proportion to the spaces occupied by the prismatic colours in the prismatic spectrum, or if they followed any other discoverable law; but those attempts met with many difficulties, the greatest of which was the choice of colours. The water colours that are commonly used, as carmine, sap-green, &c. are of so different a nature from one another, that when the balls of the thermometers were painted with them, their surfaces were not equally smooth, which occasioned great difference in the effect; for I found, that two thermometers, whose balls had been painted with the same colour, but the paint laid smoother on one than on the other, shewed different degrees of heat when they were both exposed to the rays of the Sun.

I attempted

I attempted to make thermometers with tubes of differently coloured glafs, but when a ball was formed with any of thofe tubes, the fubftance of the glafs in the ball, being much thinner than in the tube, differed very little from clear colourlefs glafs.

To include the thermometers in clofe boxes, in which the rays entered through coloured glaffes, was alfo found ineffectual; not only becaufe the colours fo tranfmitted were far from being homogeneous, but efpecially becaufe fome of thofe glaffes are much more opaque than others, even of the fame colour.

The leaft ambiguous method, therefore, was that of painting the balls of the thermometers with water-colours, taking care to lay them as equally fmooth as poffible. In this manner I repeated feveral experiments, uſing ſometimes a dozen of thermometers at once, whoſe balls were painted with various colours, and were expoſed to the Sun; and from a vaſt number of experiments, and after ſome weeks obſervation, it could be only deduced, that if the colours, with which the balls of the thermometer were painted, were pretty like the prifmatic colours, thofe thermometers ſhewed a greater degree of heat, whoſe colours were nearer to the violet in the order of the prifmatic colours, and contrarywiſe; but they were all, even that painted with white lead, in ſome

intermediate degree between the blackened thermometer and the naked or unpainted one. If the colours had not the proper degree of density, the effects were very different: thus a thermometer painted with a light blue was lower than another thermometer painted red with good carmine.

I shall now describe the manner of constructing the scales of those thermometers, which was contrived so as to be very expeditious; because some of those thermometers were often broken by some accident or other, and that new schemes often required new thermometers, to construct the scales of which in a formal manner would have required a very long time. Those methods therefore may be of use to other persons.

When the thermometers were intended to be exposed to the flame of the lamp, at a given distance from it, their scales were drawn upon slips of paper which were glued to their tubes in the manner represented by fig. 1. The thermometers were then set horizontally upon a book, so that their balls were out of the book, and at any required distances from the flame of the lamp, which distances were measured with a pair of compasses. But when the thermometers were only to be exposed to the Sun, I then used the following very expeditious method, see fig. 2. Upon an oblong board ABCD of about 14 inches by 18,
4 and

and nearly one inch thick, I pasted a piece of white paper, and delineated upon it a right-angled triangle $\triangle GEF$, one side GF of which came very near the edge CD of the board; the other side EF , which stands perpendicular to GF ; was divided into equal parts, representing degrees of FAHRENHEIT'S thermometrical scale. The lowest of those degrees was near the freezing point, and the upper was not above the 110° , it being as much as I was in want of. From the point G right lines were drawn to all the degrees in the scale EF , and many other right lines parallel to the scale EF , and consequently perpendicular to the base GF , were drawn through the whole area of the triangle. Now when the thermometers were constructed, I found, by comparison with a standard thermometer, two points whatever, which I marked with the file upon the tube, and by a note of these thermometers I knew to what degrees they answered. Thus, for instance, upon the thermometer HL two marks were made, *viz.* I answering to the 40th degree, and K to the 70th degree. Now when this thermometer was to be used I placed it upon the board $ABCD$ with the tube parallel to the scale EF , which could be easily done by the help of the parallel lines drawn upon the triangle, the ball of the thermometer being out of the board; thus I slid the thermometer backwards and forwards till the mark I ,

which was the 40th degree, coincided with the line, which went from the point G to the 40th degree on the scale, and the mark K coincided with the line which went from G to the 70th degree. In that place the thermometer was left, and in order to keep it steady, a piece of lead (o) was usually put upon the extremity of its tube. In this situation the intersections of the tube, and the lines drawn from G to the degrees in EF, shewed the degrees, or served for a scale to the thermometer HL. Thus, suppose that the quicksilver in its tube was at P, it is plain, that it was at 55° , because at that point the tube is intersected by the line which goes from G to the 55th degree on the scale EF. This board, therefore, served for a universal scale, and upon it I used to fix several thermometers at a time, and expose them all together to the Sun.

I shall conclude this paper with mentioning an experiment, which, although not thermometrical, is yet useful in removing a wrong notion some persons have concerning the effect of light.

Having seen in some book that the common black pyrophorus, or HOMBERG's pyrophorus, was impaired by light, I was desirous to try the truth of this assertion, Accordingly towards the beginning of the last year I prepared some pyrophorus, and inclosed portions of it in three glass tubes, which were immediately sealed
hermetically,

Fig. 1.

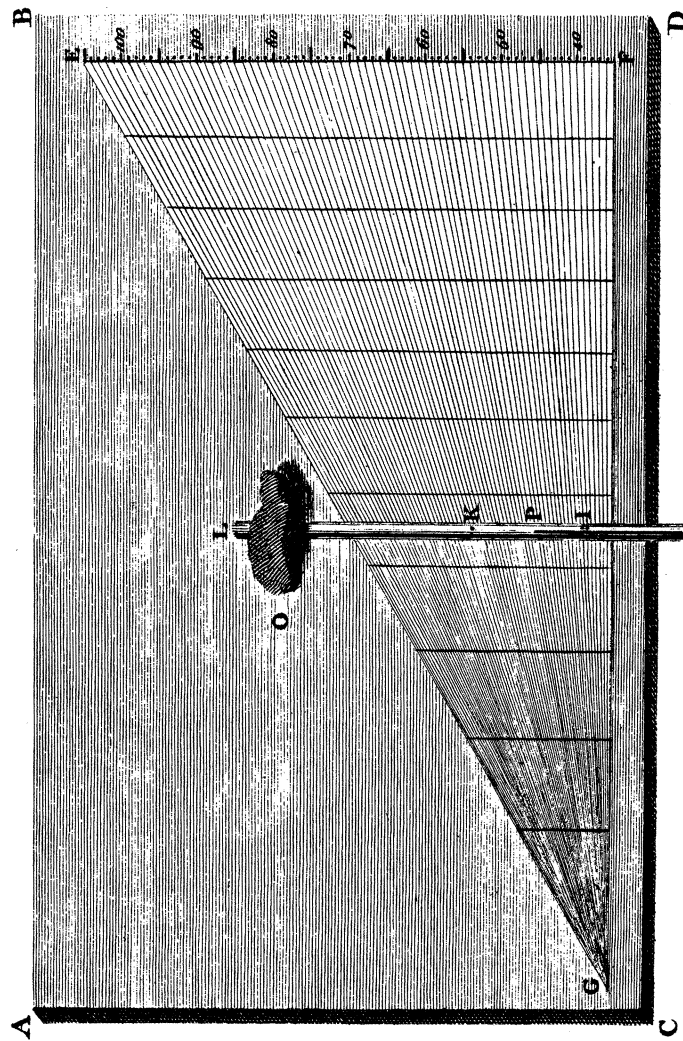
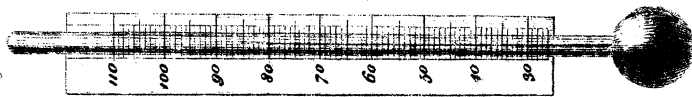


Fig. 2.



hermetically, and on the 20th of May, 1779, two of them were suspended to a nail out of a window, and the third was wrapped up in paper, and was inclosed in a box, where not the least glimmering of light could enter. In this situation they were left for above a year, and last week I broke one of those that had been kept out of the window, and that which had been in the dark, in presence of Mr. KIRWAN, F. B. S.; but the pyrophorus of each tube seemed to be equally good, taking fire within about half a minute after being taken out of the tubes, and exposed to the air upon pieces of paper, which shews that neither the presence or absence of light had injured it.

June 7, 1780.

P. S. Having mentioned to several persons my intention of making some experiments upon the temperature of the atmosphere with a new metalline thermometer, and of giving an account of them in this paper, I must here mention, that as the instrument was not finished in proper time, I shall defer giving a description of it, as well as an account of the experiments, &c. to another opportunity.

